PATENT SPECIFICATION

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(72) Inventor ROBERT JAMES CUMMINGS

(19)

(54) FRICTION WELDING

(71) We, CLARKE CHAPMAN LIMITED, a British Company of Victoria Works, Gateshead, Tyne & Wear NE8 3HS do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to friction welding and apparatus for performing friction welding.

A method of friction welding, according to the invention, comprises moving a first workpiece relative to a second workpiece while the workpieces are pressed together in rubbing contact, the relative motion being produced by applying to the workpieces orbital motions of the same rotary sense.

Throughout this specification "orbital motion" means translatory motion as distinct from rotation without translation.

Preferably, the mode of orbital motion is circular, but orbital motion in non-circular modes is possible within the scope of the invention.

The axis, or effective axis in the case of non-circular motion, about which one workpiece orbits may be different from that about which the other workpiece orbits, but preferably the workpieces orbit about a common axis or effective axis.

The two workpieces preferably move at the same speed.

The phase difference or effective phase difference between the orbits of the two workpieces is preferably 180 angular degrees (180°).

With a phase difference of 180° and where the workpieces move in circular orbits about a common axis, the mode of relative rubbing motion is circular and the speed of relative rubbing motion is the sum of the speeds of the orbital motions applied to the workpieces and it is preferred to use that form of method, but other forms of the invention are possible.

The invention is particularly advantageous, though is not limited in application to the case, where it is required that the workpieces, when in their final friction welded joined condition, occupy predetermined positions relative to each other. For example, the workpieces may be required to be aligned with each other. Whatever the final position, whether it be predetermined or not it is preferred that the elimination of relative rubbing comprises the reduction to zero of the amplitudes of the applied orbital motions about a common axis, or common effective axis; or the reduction to zero of the phase difference between the applied orbital motions about a common axis or common effective axis; or where the applied orbital motions occur about spaced axes, or spaced effective axes, the reduction to zero of both the amplitudes of the applied orbital motions and the distance between the axes, or effective axes; or the reduction to zero of both the phase difference between the applied motions and the distance between the axes, or effective axes; or some other combination of those steps.

In other forms of the method, the relative rubbing may be eliminated by decelerating the applied orbital motions to zero speed.

Apparatus for performing the method according to the invention comprises two workholders, means for applying orbital motions to the workholders and for causing relative movement of the workholders transversely of the planes of orbital motion, in which said orbital motions can be applied to the workholders in the same rotary sense.

Some forms of the method and how it can be performed will now be described by way of example to illustrate the invention with reference to the accompanying drawings, in which:—

Figures 1 to 5 are diagrammatic representations of two rubbing workpieces showing different stages of movement;

Figure 6 is a diagrammatic schematic side elevation illustrating in broad terms apparatus for performing the method;

Figure 7 is a diagrammatic schematic side elevation illustrating in broad terms apparatus with parts omitted, for performing the method and showing one form in principle only of drive means for the apparatus;

Figure 8 is a diagrammatic schematic section through part of the apparatus shown in Figure 7; and

Figure 9 is a diagrammatic schematic side elevation of a modified form of part of the apparatus shown in Figure 7.

Figure 1 (a) shows two workpieces 10, 12 which are shown as cylindrical for simplicity, but workpieces of other shapes can be welded together by the method according to the invention. The workpieces 10, 12 are shown with their end faces 14, 16, respectively, in rubbing contact over an area 18.

The workpiece 10 is subjected to an applied clockwise orbital motion about an axis 20. The locus of the centre 22 of the workpiece 10 is shown as a circle 24 centred on the axis 20.

The workpiece 12 is subjected to an applied clockwise orbital motion about the axis 20 and the locus of the centre 26 of the workpiece 12 is also represented by the circle 24.

The speeds of the orbital motions applied to the workpieces 10 and 12 are the same and the two motions have a phase difference of 180°, the centres 22, 26 always being at opposite ends of a diameter of the circle 24.

The workpieces do not rotate about their centres 22, 26 but maintain the same relative angular orientation, as shown at (b), (c) and (d) where the positions of the workpieces are shown after they have both orbited 90°, 180° and 270°, respectively, from their positions shown in (a), and points 30 and 32 on the workpieces 10 and 12, respectively, are shown as always remaining vertically above the centres 22, 26, respectively, of the two workpieces.

The instantaneous rectilinear directions of movement of the two workpieces 10, 12 at the positions shown at (a), (b), (c) and (d) are indicated by arrows and, as can be seen, the two workpieces are always moving in opposite instantaneous rectilinear senses. The mode of relative movement that is, the mode of relative rubbing in the area 18 is circular and since the two bodies are always moving in opposite instantaneous rectilinear senses the relative linear speed of rubbing is twice the applied linear speed. In other words, the relative angular velocity of rubbing is twice the angular velocity of the workpieces about the axis 20.

The workpieces 10, 12 may be brought into contact over an area corresponding to the area 18 at rest and then the orbital motions may be applied simultaneously to the workpieces. The workpieces 10, 12 are forced together so that friction between the rubbing faces produces sufficient heat to cause the faces to become plastic and suitable for welding. When that occurs the rubbing is discontinued. If necessary the workpieces can be forced together under greater pressure when the surface conditions become suitable for welding. Many different regimes of pressure can be followed depending on the characteristics of the workpieces and the invention is not concerned with that aspect of friction welding.

If the workpieces are not required to occupy any particular position in relation to each other in their final welded state, then the rubbing can be eliminated simply by decelerating both orbital motions to zero

The invention will also be adopted where the two workpieces are required to occupy a particular position in relation to each other in their final welded state. For example, the two workpieces may be required to be aligned, that is, their centres 22, 26 may be required to be coincident in the final welded stated.

This can be achieved in various ways. Figure 2 shows one way. At (a) the workpieces 10, 12 are shown at a final stage in their normal rubbing mode at which the amplitude of relative rubbing is begun to be decreased. This is achieved by decreasing the amplitude of both orbital motions so that at (b), during the 90° of orbiting following the positions at (a), the amplitudes have decreased to say half so that the centres 22, 26 are much closer together. At (c) after a further 90° of orbital motion the centres 22, 26 are still closer and at (d) the centres 22 and 26 are both coincident with the axis 20 and the workpieces are aligned both orbital motions and the relative rubbing motion having ceased.

Figure 3 shows another way in which alignment can be achieved. The position at (a) corresponds to (a) in Figure 2 and the amplitude of relative rubbing is begun to be decreased by decrease of the angular phase difference between the two applied orbital motions. This is shown by deceleration of the orbital motion applied to the workpiece 12, the centre 26 of which by the time the position at (b) has been reached is only 135° ahead of the centre 22 of the workpiece 10. At the position (c), the centre 26 is only 90° ahead of the centre 22. At the position (d) the centre 26 is only 45° ahead of the centre 22. At the position (d) the centres 22 and 26 coincide and the workpieces are aligned. Relative rubbing has ceased but both workpieces continue to orbit about the axis 20 until brought to rest.

Although the orbital motion of the centre

26 is effectively decelerated it is equally true that the same effect can be achieved by a mere geometrical adjustment of the centre 26 or of the centre 22 or of both centres so that their spacing about the orbital circle 24 is reduced to zero. The method need not involve any application of any particular predetermined deceleration as such, though deceleration is of course effectively involved as the result of such geometrical adjustment. If desired, of course, the application of deceleration as such can be employed.

In the method shown in Figure 3, the final common centre or axis is an axis different from the axis 20 and there is possible disadvantage in the fact that the welded workpieces exert a couple about the axis 20. By contrast, in Figure 2, the welded workpieces are aligned on the axis 20. However, the method shown in Figure 3 can be achieved by simple adjustment of the centre of only one workpiece if desired, whereas in Figure 2 it is necessary to adjust the amplitude of motion of both workpieces.

In Figures 1 to 3 and also in Figures 4 and 5 to be described next the radius of the circle 24 has been shown relatively large compared with the radii of the workpieces but this is for clarity. In practice the radius of the circle 24 would be relatively much smaller and the area 18 of rubbing would be a much larger proportion of the area of each end face of each workpiece. The illustrations are therefore purely diagrammatic and for the purpose of illustration only.

Figure 4 shows stages in the movements of the workpieces 10, 12 under applied orbital motions in the same rotary sense about the axis 20 where the phase difference is only 90°. Clearly the workpieces instantaneously are moving in rectilinear directions at right angles to one another so that the speed of relative rubbing is not the sum of the applied speeds, but it is a speed of magnitude greater than either applied speed though less than the arithmetic sum of the applied speeds.

The maximum speed of relative rubbing is that occuring when the phase difference is 180° as explained with reference to Figures 1, 2 and 3.

Figure 5 shows stages in the movements of the workpieces 10, 12 under applied orbital motions in the same rotary sense about separate parallel axes 20, 21, respectively, spaced apart a distance "d", the orbital motions having a phase difference of 180°. The two workpieces 10, 12 are always moving in opposite instantaneous rectilinear senses so that the magnitude of the relative speed of rubbing is the sum of the speeds of the applied motions.

The termination of rubbing in the case of the form of the method shown in Figure 5, would involve bringing the axes 20 and 21 into coincidence if it were required that the workpieces be in aligned positions at the end of friction welding. In addition the workpieces centres 22, 26 would have to be brought into coincidence as described above in relation to Figure 2 or Figure 3.

In general, the final predetermined positions of the workpieces relative to each other may be either such that the axes of the workpieces, or the centres are aligned (i.e. zero spacing between them); or the relative positions may be such that the axes, centres or other points of the workpieces are spaced apart.

It may be sufficient merely to eliminate rubbing without regard to final positions; or the final position may involve achieving predetermined positions of the workpieces relative to each other in which there is either zero spacing between axes or some spacing.

The linear speeds of motion of the workpieces in their orbits are in some preferred forms of the invention the same. However, the speeds may be different. For example, the speeds may differ by an amount or by successive amounts of change such that, when the rubbing stage or stages has or have been completed, a phase difference which existed at the start of rubbing has been reduced (for example reduced to zero) to ensure that the final relative positions of the workpieces are as desired. In such a case the phase difference between the motions of the workpieces is not constant. The phase difference, if any, may vary in other ways during rubbing for example from zero to a maximum and then back to zero depending on the speed difference between the motions or speed changes effected during rubbing. The change in phase difference which can be effected by the gear mechanism described below particularly with reference to Figure 8 involves a change in speed, for example. However, the speed of one or other or both of the motions of the workpieces may be changed by change in speed of the applied rotary drive in any desired way instead of, or in addition to, the changes effected by the gear mechanism.

The linear speeds of motion of the workpieces may be the same even though the common value of the speeds changes or reduces to zero.

Relative rubbing may be terminated by any convenient combination of the steps described above, or by any one of such steps. If required, predetermined positions of the workpieces relative to one another can be achieved by the use of similar steps or combination of steps but the steps are then taken with due regard to the final

relative positions required.

Figure 6 shows very broadly the main parts of a machine for performing the method. It comprises a base 100 supporting two welding heads 102, 104. The head 102 is fixed relative to the base 100 but the head 104 can move towards and away from the head 102 on slides 106 on the base 100 under the action of a hydraulic ram 108.

The heads 102, 104 have respective workholders 110, 112 which are adapted to hold workpieces 114 and 116, respectively. The workholders 110, 112 can be subjected to orbital motions in the same sense about the same or spaced axes by means of powered drive mechanism (not shown) within the heads. The applied motions can be as described above, for example. The workpieces are forced together by the ram 108 and when rubbing results in conditions suitable for welding the rubbing is terminated as described above. If necessary the ram force is increased at this stage to increase the pressure between the workpieces. Although several workpieces are shown held by each workholder, it is of course possible to weld but two workpieces one in each holder, or to use a machine having workholders suitable for holding but one workpiece. However, orbital welding is particularly suitable for mass production where machine utilisation is improved by simultaneous welding of several pairs of workpieces.

Figure 7 shows in broad terms how a friction welding machine for performing the method may be driven. Figure 7 shows a base 200 supporting a fixed head 202 and a sliding head 204. Ram means for moving the head 204 are omitted for clarity. A shaft 206 is connected at one end to a planetary gear system 208 having a shaft 210 connected by gearing 212 to a shaft 214 driven by a motor (not shown) within the fixed head 202. The shaft 214 carries an eccentric 216 on which is mounted a workholder 218. The workholder 218 is prevented from rotating by a restraint 220 which, however, allows the workholder to move orbitally.

At the other end, the shaft 206 is formed as, or is connected to, a ball-spline shaft means 222, on which is mounted a gear 224. The gear 224 meshes with a gear 226 secured to one end of a shaft 228 driven by a motor (not shown) within the sliding head 204. The sliding head and gears 224 and 226 are movable by the ram means as a unit relative to the ball-spline shaft 222. The other end of the shaft 228 carries an eccentric 230, on which is supported a workholder 232 having a restraint 234.

Bearings 240 are provided between the workholders 218 and 232 and their respective ecentrics.

Figure 8 broadly shows the internal arrangements of the gear system 208, its casing being omitted. The shaft 206 is connected to a planet gear carrier 240 carrying two planet gears 242, 244, which mesh with the internal teeth of a fixed ring gear 246 and with a sun gear 248. The shaft 210 similarly has a carrier 250, planet gears 252, 254, meshing with a rotatable ring gear 256 and also meshing with the sun gear 248. Means (not shown) are provided for holding the ring gear 256 fixed and for rotating it.

The workholders 218, 232 move orbitally when the motors in their respective heads 202, 204 are energised and so long as the ring gear 256 is fixed the two workholders orbit at the same speeds since their motions are synchronised by the shaft 206, gear system 208, gearing 212 and the gears 224, 226.

If the ring gear 256 is rotated while the workholders 218, 232 are moving orbitally, then change in the relative motion of the two workholders is introduced. The phase relationship (explained above) between the two workholders is thus changed. For example, the workholders may be orbiting with a phase difference of 180°. By rotation of the ring gear 256 the phase difference can be reduced progressively to zero while both workholders continue to orbit. This facility can be used to bring rubbing workpieces, mounted in the respective holders, into alignment or into a desired relative position as the final stage of friction welding is reached, the workpieces being forged together in alignment or in that relative position at the instant relative motion between them ceases, which occurs when the phase difference reaches zero. An explanation of this facility has already been given above with reference to Figure 3. The final aligned or other relative position of the friction welded workpieces is accurately determined before welding begins by correct relative positioning of the workpieces on the holders. The holders themselves would always occupy the same relative positions when the phase difference between them is reduced to zero.

The lengthy description of alignment of workpieces has been given because of its great importance in orbital friction welding, since one of the chief advantages of this form of friction welding is the possibility it gives of achieving predetermined final relative positions and relative orientations of workpieces. However, the method described in detail is only by way of example, though it is a preferred example. Other ways of using the facility of phase difference change may prove advantageous in other forms of the method according to the invention.

As an alternative to separate motors in each head, a single motor can be used, for

example connected to the shaft 206 at or adjacent its mid point.

Figure 9 shows how the restraints 220, 234 may be eliminated. Figure 9 shows a head 300 which may represent either head 202 or 204, both being the same as shown in Figure 9. The gear 302 may be the equivalent gear in the gearing 212 or may be the gear 226. The gear 302 is connected by a shaft 310 to a gear 306, which meshes with two similar gears 308. They are secured to like ends of shafts 312, 314, respectively, which extend through the head 300 and carry at their other ends eccentrics 316, 318, respectively. The eccentrics 316, 318 have bearings 320, 322, respectively, on which is mounted a holder 330 replacing the holder 218 or 232 in the former arrangement. The eccentrics 316, 318 rotate in phase at the same speeds to orbit the holder 330.

A drive motor (not shown) within the head 300 may be connected to the shaft 310 or to the shafts 312, 314.

In figures 7 and 9 the holders have been shown engaging front faces of the eccentrics at which thrust exerted by the ram of the moving head 204 is supported. However, the figures are purely diagrammatic in this respect. Some, or all, or no thrust may be so supported at the holders. Thrust bearings may be provided to take all ram thrust so as to relieve the eccentrics of such thrust entirely, or to relieve the eccentrics partly of such thrust. Where thrust is exerted on the eccentrics suitable thrust bearing means would be provided between the holder and the eccentrics where necessary, though none is shown in the drawings.

Although the applied orbital motions described above are circular motions, it is possible to use one or more applied orbital motions which are non-circular.

In a modification (not shown), both heads of the machine can be slidable on the base towards and away from one another. In this instance, both heads and their associated gearing can be mounted for sliding movement, for example, in the same manner as head 204 described with reference to Figure 7.

For example, an elliptical orbital motion or motions can be used. In that case the motion may be considered to have an effective axis which is at the centre of the ellipse that is the mid-point of the line joining the foci of the ellipse.

The relative speed of rubbing is the arithmetic sum of the magnitudes of the applied speeds (where the phase difference is 180°) or (where the phase difference is between 90° and 180°) is a sum derived vectorially and less than the arithmetic sum of the applied speeds but is always greater than the speed applied to either workpiece. This gives the advantage that the speeds of the components of the drive mechanisms used to produce the orbital motions can, for a given desired relative speed of rubbing, be less than they would be if one workpiece were fixed. If one workpiece is fixed, the drive mechanism components would be required to have speeds of the order of twice the speeds of components in the mechanism used in the present invention. Therefore, the design of the mechanisms and components is simplified and their duties are less arduous. The speed of rubbing for successful friction welding is dictated by the material of the workpieces and their other characteristics and the production times required in a particular plant, but in many cases the speeds required would impose very onerous duties on the components of the drive mechanisms used for producing orbital motions of but one workpiece, the other remaining fixed.

The invention can be applied to the joining of workpieces of non-circular section since the workpiece can be maintained in a predetermined relative angular orientation throughout rubbing, which means that they merely require their axes to be aligned at the end of rubbing to ensure a uniform matched cross-section in the finished product, no angular adjustment about their axes being required.

The invention can be applied to the joining of workpieces of different cross-sections.

The invention can be applied where different materials or the same materials are to be welded together and the materials may be metal or non-metal such as plastics or glass or other ceramic material for example.

Examples of methods and apparatus for producing orbital motions and for reducing amplitudes to zero are described and claimed in our British patents Nos. 1,293,531, 1,315,676 and 1,324,431.

The machines described above may be modified so that the workholders orbit in horizontal planes, the ram axis being vertical. The machine may be modified in another way to allow one workholder to hold only one large workpiece to which several smaller workpieces held by the other workholder are welded.

WHAT WE CLAIM IS:—

1. A method of friction welding comprising moving a first workpiece relative to a second workpiece while the workpieces are pressed together in rubbing contact, the relative motion being produced by applying to the workpieces orbital motions of the same rotary sense.

2. A method according to claim 1, in which the orbital motions are circular.

3. A method according to claim 1, in

which the orbital motions are non-circular.

4. A method according to any preceding claims, in which the axis or effective axis about which each workpiece orbits is an axis common to the two motions.

5. A method according to any preceding claim, in which the speeds of the orbital motions of the two workpieces are the same.

6. A method according to any preceding claim, in which the phase difference or effective phase difference between the orbital motions of the two workpieces is 180 angular degrees.

7. A method according to any claim of claims 1 to 3 or 5 or 6, in which the orbital motions are about separate axes.

8. A method according to any preceding claim, in which the elimination of relative rubbing between the workpieces comprises reduction of the amplitude of applied orbital motions.

9. A method according to claim 8, in which said amplitudes are reduced to zero.

10. A method according to any claim of claims 1 to 7, in which the elimination of relative rubbing between the workpieces comprises reduction of the phase difference between the applied orbital motions.

11. A method according to claim 10, in which said phase difference is reduced to zero.

12. A method according to any claim of claims 1 to 7, in which the elimination of relative rubbing between the workpieces comprises deceleration of the applied orbital motions to zero speed.

13. A method according to claim 7, in which the elimination of relative rubbing between the workpieces comprises reduction in the distance between said axes.

14. A method according to claim 13, in which said distance is reduced to zero.

15. A method according to any preceding claim, in which the workpieces when in their final friction welded joined condition occupy pre-determined positions relative to each other.

16. Apparatus for performing the method according to any preceding claim comprising two workholders, means for applying orbital motions to the workholders and for causing relative movement of the workholders transversely of the planes of orbital motion, in which said orbital motions can be applied to the workholders in the same rotary sense.

17. Apparatus according to claim 16, for performing the method according to any of claims 2, 4 to 7, 10 or 11, in which respective mechanisms are provided by which said orbital motions can be applied to the workholders, and in which adjustable gear mechanism is provided by which the phase difference between said orbital motions can be changed.

18. Apparatus according to claim 17, in which said gear mechanism is a planetary gear system.

19. Apparatus according to claim 18, in which said respective mechanisms are connected through gearing to respective shafts of said planetary gear system.

20. Apparatus according to any claim of claims 17 to 19, in which said respective mechanisms are drivable by respective heads, at least one of which is slidably mounted on a base for motion towards and away from the other head, and in which ram means is provided for moving said slidably mounted head relative to the base.

21. Apparatus according to claim 16, in which said means for applying orbital motions to the workholders are such as to enable the amplitude of motion to be changed.

22. Apparatus according to claim 16, in which said means for applying orbital motions to the workholders are capable of deceleration.

23. Apparatus according to claim 16, in which said workholders are relatively movable transversely to the axis or axes or the effective axis or axes of the orbital motions.

24. A method of friction welding according to claim 1, substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

25. A method of friction welding according to claim 1, substantially as hereinbefore described with reference to Figures 1 and 3 of the accompanying drawings.

26. A method of friction welding according to claim 1, substantially as hereinbefore described with reference to Figure 4 of the accompanying drawings.

27. A method of friction welding according to claim 1, substantially as hereinbefore described with reference to Figure 5 of the accompanying drawings.

28. A method of friction welding according to claim 1, substantially as hereinbefore described with reference to Figures 1, 3 and 6 of the accompanying drawings.

29. A method of friction welding according to claim 1, substantially as hereinbefore described with reference to Figures 1, 3 and 7 to 9 of the accompanying drawings.

30. Apparatus for performing the method according to claim 1, substantially as hereinbefore described with reference to Figure 6 or Figures 7 to 9 of the accompanying drawings.

ROBERT J. CUMMINGS,
Chartered Patent Agent.
Agent for the Applicants.

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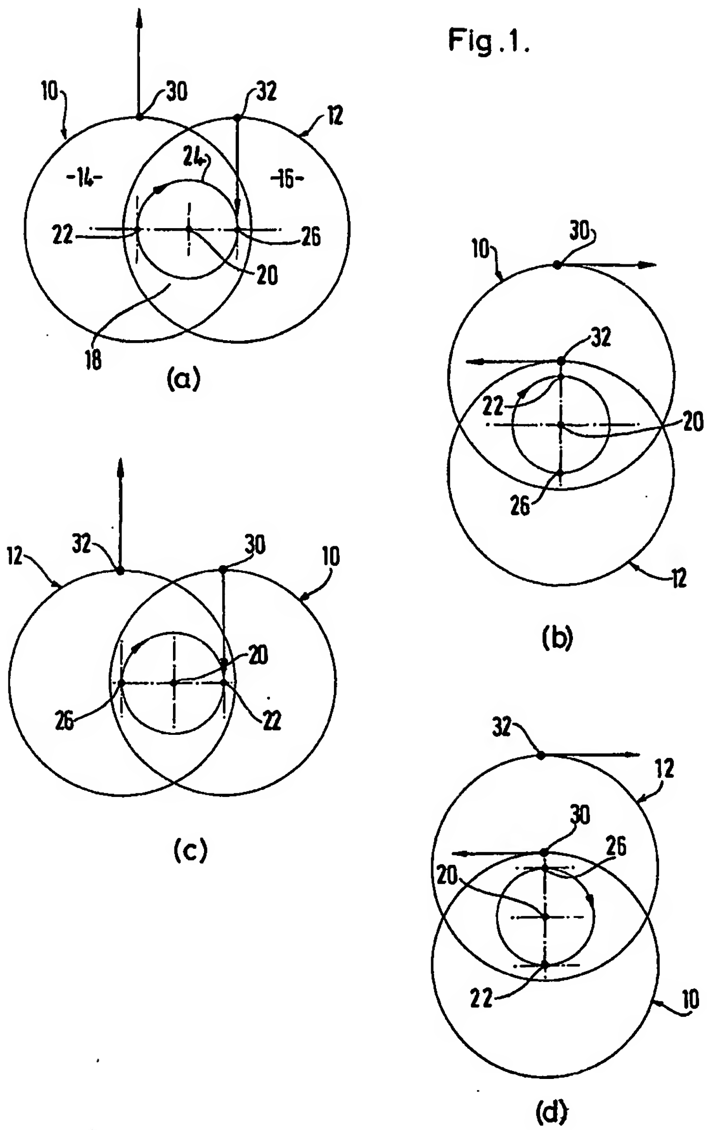
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Fig.1.

Fig.2.

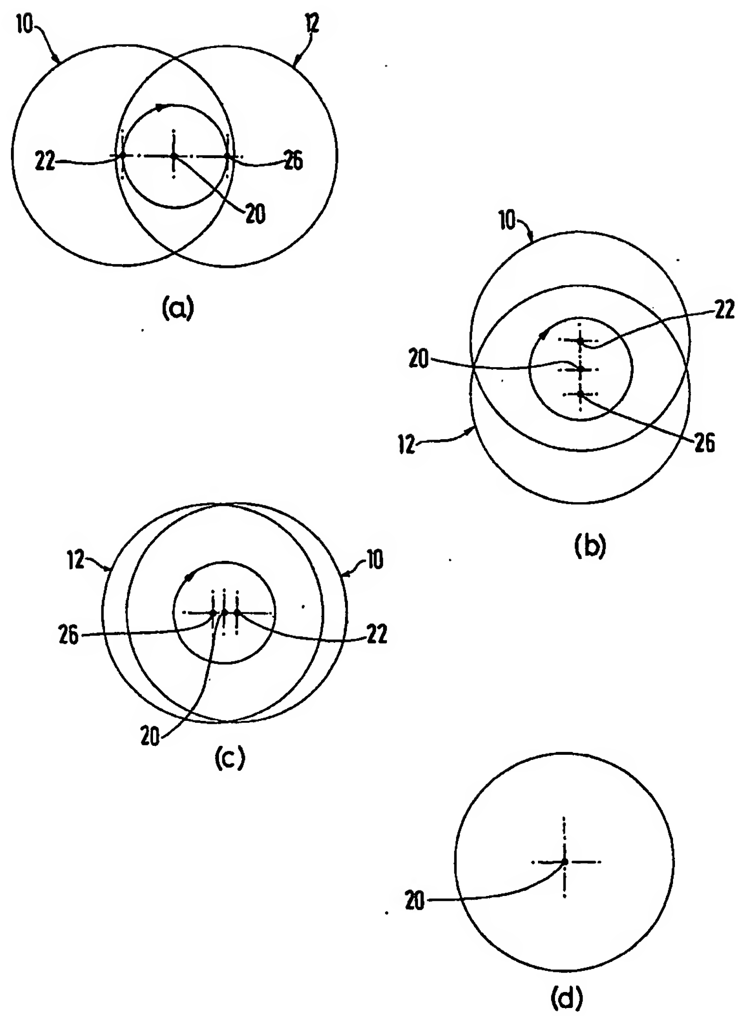
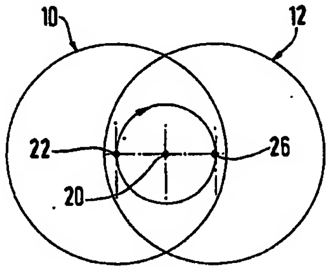


Fig .3.



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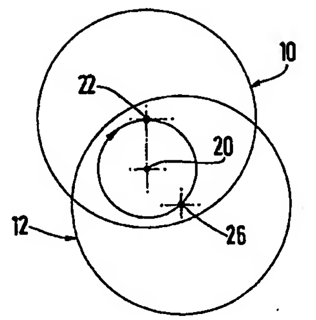

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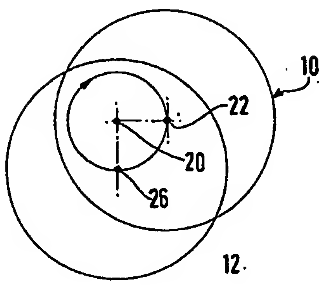

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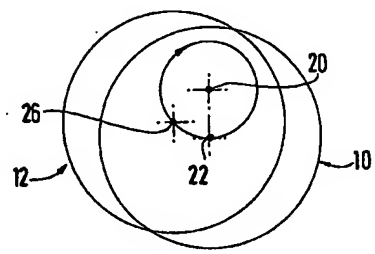

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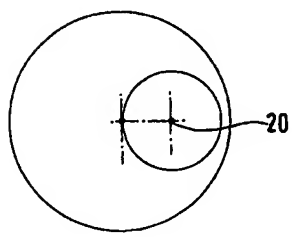

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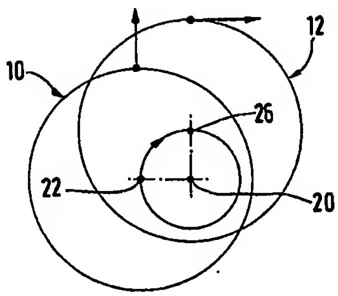
Fig. 4.



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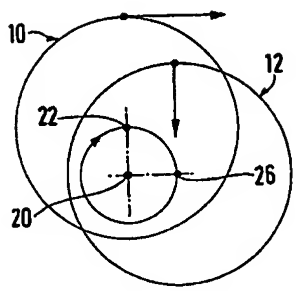

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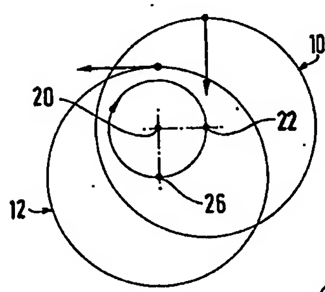

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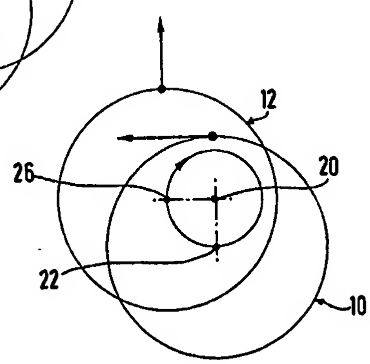

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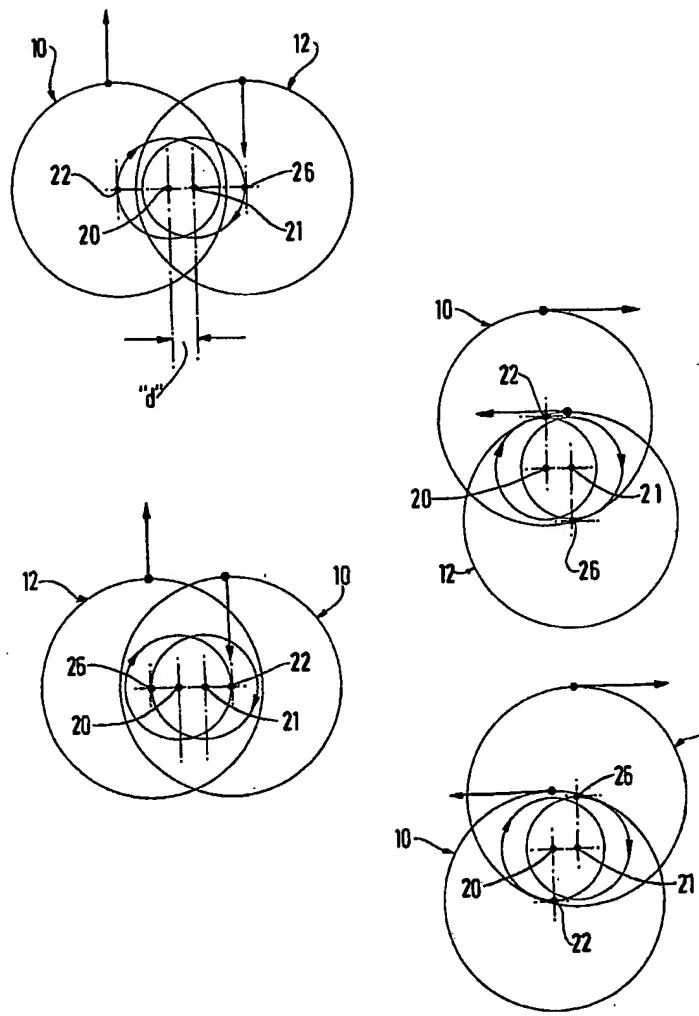
Fig. 5.



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Sheet 6

Fig.6.

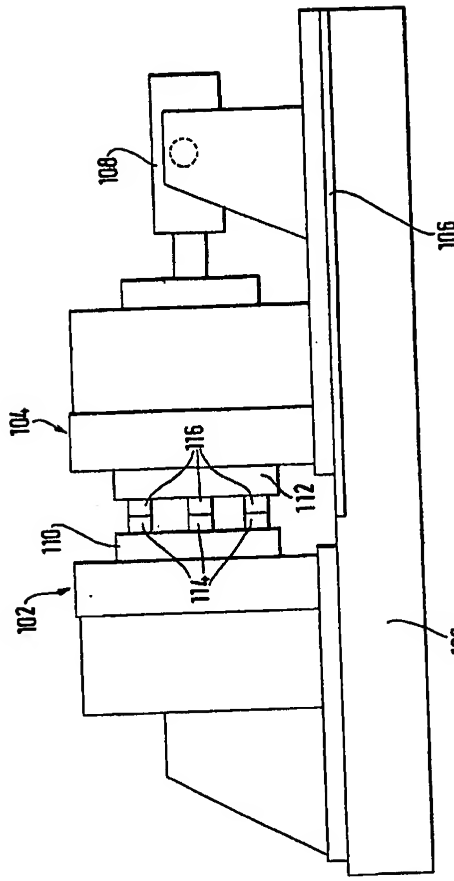

Fig. 7.

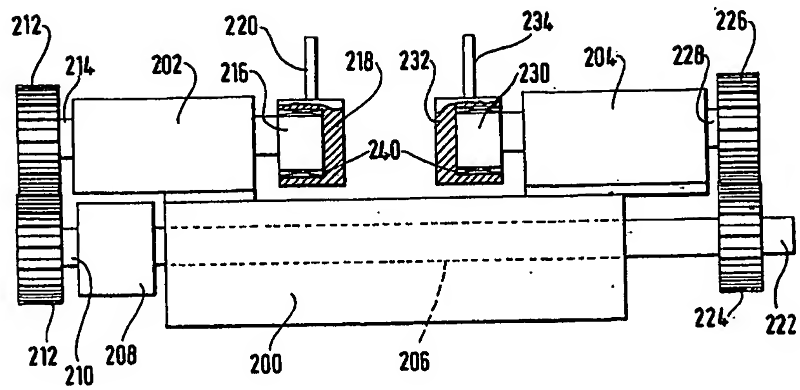
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Fig. 9.

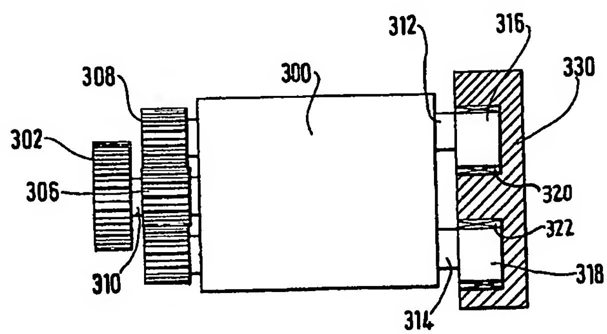
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Fig. 8.